Stochastic search process under resetting

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The optimization of search processes using various protocols has garnered significant attention recently, with resetting-mediated dynamics proving to be an especially effective approach for shortening the completion time of complex search processes. Resetting typically operates by halting an ongoing process at a specific rate and returning it to a predefined state, effectively constraining trajectories that deviate far from the target. While this confinement introduces anomalous non-equilibrium behavior, it simultaneously enhances the speed of search processes by eliminating longer, time-consuming paths. We investigate the mean cover time and the probability density function (PDF) of the cover time for a finite interval of size L using a single continuous one-dimensional Brownian motion. One of the important quantity to define the efficiency of any search process is the mean cover time. We have investigated the impact of resetting on the mean cover time.

Name: Archak Purkayastha

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Title: Non-Markovian Quantum Mpemba Effect

Abstract:

Since its rediscovery in the twentieth century, the Mpemba effect, where a far-from-equilibrium state may relax faster than a state closer to equilibrium, has been extensively studied in classical systems and has recently received significant attention in quantum systems. Many theories explaining this counter-intuitive behavior in classical systems rely on memory effects. However, in quantum systems, the relation between the Mpemba effect and memory has remained largely unexplored. Here, we consider general non-Markovian open quantum systems and reveal new classes of quantum Mpemba effects, with no analog in Markovian quantum dynamics. Generically, open quantum dynamics possess a finite memory time and a unique steady state. We show that, due to non-Markovian dynamics stemming from system-bath correlations, even if the system is initialized in a state identical to the steady state, it can take a long time to relax back. Contrarily, it is possible to find other initial states that reach the steady state much faster. Most notably, we demonstrate that there can be an initial state in which the system reaches the steady state within the finite memory time itself, therefore giving the fastest possible relaxation to stationarity. We verify the effect for quantum dot systems coupled to electronic reservoirs in equilibrium and non-equilibrium setups at weak, intermediate and strong coupling, and both with and without interactions. Our work provides new insights into the rich physics underlying accelerated relaxation in quantum systems.

Ref: arXiv:2402.05756 (Accepted in PRL)

Title: Steady state occupation and quantized transport in Floquet systems

Speaker: Arijit Kundu, IIT Kanpur

Abstract: Steady state density matrix and occupation of Floquet states remains an interesting question, although several developments have been made in recent times. I'll discuss the appearance of a stair-case occupation probability of Floquet states and what kind of quantized response it can lead to. This system is now dubbed as a 'Floquet fermi liquid', where counterparts of equilibrium Fermi-liquid nature of the underlying states can be recovered through correlations.

Title: Ergodicity breaking in the Thermodynamic Limit: Dynamical Freezing and Emergent Conservation Laws

Arnab Das

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Abstract: An interacting, closed quantum system, when driven periodically by changing a parameter of the Hamiltonian periodically with time, is expected to heat up without bound and to reach a locally infinite-temperature like random state – a scenario known as 'Floquet thermalization'. This expectation is consistent with the ergodicity principle of Statistical mechanics, Fermi's Golden-rule-type arguments for heating of a Floquet system. etc. Here we present a generic exception to this scenario under strong drive – the phenomenon of dynamical freezing. We show, strong drive gives birth to new approximate but stable conservation laws not present in the undriven system. These conservation laws prevent Floquet thermalization, and opens door to Floquet engineering of new phases of quantum matter in interacting quantum systems, which was previously believed to be impossible.

Sublattice scars in a two-dimensional $U(1)$ quantum link model

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We discuss the structure and properties of a class of anomalous high-energy states of matter-free $U(1)$ quantum link gauge theory Hamiltonians using numerical and analytical methods. Such anomalous states, known as quantum many-body scars in the literature, have generated a lot of interest due to their athermal nature. We demonstrate the formation of such scars from the superposition of exact zero modes in a particular $U(1)$ gauge theory. In particular, a class of such anomalous eigenstates, which we dub as *sublattice scars*, seem to be perfectly structured if a particular local observable is probed, even though these states are high-energy eigenstates. A "triangle relation" that connects some anomalous zero modes with other states with nonzero integer eigenvalues will be discussed.

Name: Arti Garg
Affiliation: Saha Institute of Nuclear Physics

Title: Periodically driven quantum many-body systems

Abstract: In this talk I will discuss some of the ongoing works on periodically driven quantum many body systems. To be specific I will discuss the realization of discrete time crystals in Sherrington-Kirkpatrick model of Ising glass and compare the stability of the discrete time crystal phase here with that in the spin systems with uniform power-law interactions. On a very different note, I will also discuss our recent work on drive induced half-metallicity in Hubbard type models.

Name: Atanu Rajak, in collaboration with Soumadip Pakrashi and Sambuddha Sanyal, IISER Tirupati

Affiliation: IIT Hyderabad

Title: Drive induced universal freezing in quasiperiodic chains

Abstract: In a tight-binding model, localization arises from suppressing the coherent superposition of localized Wannier orbital wavefunctions caused by sufficiently large differences in on-site potentials relative to the hopping amplitude. This delicate condition of localization can be broken by a strong enough time-periodic perturbation that can “melt” localization by restoring the Wannier wave function hybridization, however by choosing a special drive protocol localization can be also restored by dynamical “freezing” at resonant drive frequencies. We address the question of arisal of complete localization by engineering through an external time-periodic drive in a disordered system, regardless of a system’s static properties. In this work, we demonstrate a universal dynamical freezing regime induced by staggered time periodic modulation of the bond lengths of a generalized quasi-periodic Aubry-Andre model. Our asymptotically exact numerical results show that the periodic drive-induced dynamical freezing regime doesn’t depend on the static properties of the model or the discrete or continuum nature of the drive. We find that the universal dynamical freezing regime is a non-perturbative effect but employing two different perturbative approaches we propose a mechanism for the same that suggests a competition between drive induced infinite-range tunneling at infinite order of perturbation and crystalline symmetry breaking onsite potential.

Irreversibilty and transience in a model of many sokobans and boxes on a line

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We consider a simple model of many sokobans and boxes on a finite line. The sokobans do a random walk to neighboring empty sites. If the site is occupied by a box, but the next site is empty, the sokoban can push push the box to the empty site, and move to the now emptied site. This model shows irreversibility, as if two adjacent sites are both occupied by boxes, these boxes can not be moved at any later time. The long time steady state is strongly non-ergodic, and the system gets trapped, and can make transitions within a very small subset of states. We characterize this decomposition of phase space into disconnected sectors, and also study the hierarchical structure of transient states, where states at a level, can either move amongst themselves, or go to states at a lower level. We use generating function techniques to determine exactly the number of disconnected components, the number of configurations in a component, the number of transient configurations at different heights, and the sector-decomposition of recurrent states in this model.

Name: Dibyendu Roy

Affiliation : Raman Research Institute, Bangalore

Title: Spectral form factor in the chaotic phase of generic periodically kicked interacting quantum many-body systems

Abstract: I shall discuss the emergence of random matrix theory (RMT) spectral correlations in the chaotic phase of generic periodically kicked interacting quantum many-body systems by analytically calculating spectral form factor (SFF) up to two leading orders in time. The presence or absence of time-reversal symmetry will be considered in investigating all three of Dyson's symmetry classes. I shall explain how (e.g., the mechanism, nonuniversal behavior) and when (timescales) many-body quantum systems acquire a universal RMT form. We have developed an ingenious scheme to include contributions to the SFF from many diagrams of different permutations of basis states. We provide general rules to calculate the contribution of various diagrams and discover reduced diagrams that contain information on the contribution to the SFF in the ergodic phase. Our results for the SFF give the universal SFF at a longer time and the nonuniversal part of SFF at a short time, which goes beyond the RMT predictions.

Various phases of discrete time crystal in driven central spin model

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Abstract: We propose and characterize a driving protocol for an interacting central spin system to establish a perfect period doubling time crystal phase at certain values of interaction strength for any initial state and any system size. The nature of the time crystal depends on the odd-even parity of the number of satellite spins and the value of the central spin. Alongside the numerical simulation, we provide an analytical explanation for this behavior. Then we explore the sensing capability of this system to measure the interaction between the central spin and the satellite spins. The time crystal phase shows enhanced sensitivity as we see the Quantum Fisher Information scales as N^2 (N being the system size). Along with this, we find some period 4, period 12 and period 24 time crystal at some finely tuned values of interaction strength.

Entanglement asymmetry and quantum Mpemba effect in closed driven quantum systems

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IACS, Kolkata

We shall discuss the dynamics of entanglement asymmetry in periodically driven quantum systems using a periodically driven XY chain as a model for a driven integrable quantum system. We shall provide semi-analytic results for the behavior of the dynamics of the entanglement asymmetry, ΔS, as a function of the drive frequency and identify special drive frequencies at which the driven XY chain exhibits dynamic symmetry restoration and displays quantum Mpemba effect over a long timescale. We shall identify an emergent approximate symmetry in its Floquet Hamiltonian which plays a crucial role for realization of both these phenomena. We follow these results by numerical computation of ΔS for the non-integrable driven Rydberg atom chain and obtain similar emergent symmetry-induced symmetry restoration and quantum Mpemba effect in the prethermal regime. Finally, time permitting, we shall provide an exact analytic computation of the entanglement asymmetry for a periodically driven conformal field theory (CFT) on a strip. Such a driven CFT, depending on the drive amplitude and frequency, exhibits two distinct phases, heating and non-heating, that are separated by a critical line. Our results show that for m cycles of a periodic drive with time period T, $\Delta S \sim \ln mT$ [$\ln(\ln mT)$] in the heating phase [on the critical line] for a generic CFT; in contrast, in the non-heating phase, ΔS displays small amplitude oscillations around it's initial value as a function of mT. We provide a phase diagram for the behavior of ΔS for such driven CFTs as a function of the drive frequency and amplitude.

Quantum Incompatibility in Parallel vs Antiparallel Spins

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We investigate the joint measurability of incompatible quantum observables on ensembles of parallel and antiparallel spin pairs. In parallel configuration, two systems are identically prepared, whereas in antiparallel configuration each system is paired with its spin-flipped counterpart. We demonstrate that the antiparallel configuration enables exact simultaneous prediction of three mutually orthogonal spin components—an advantage unattainable in the parallel case. As we show, this enhanced measurement compatibility in antiparallel configuration is better explained within the framework of generalized probabilistic theories, which allow a broader class of composite structures while preserving quantum descriptions at the subsystem level. Furthermore, this approach extends the study of measurement incompatibility to more general configurations beyond just the parallel and antiparallel cases, providing deeper insights into the boundary between physical and unphysical quantum state evolutions. To this end, we discuss how the enhanced measurement compatibility in antiparallel configuration can be observed on a finite ensemble of qubit states, paving the way for an experimental demonstration of this advantage.

Collective Excitation of Dipolar Rotating Trapped Bose Atoms

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Collective excitation of strongly correlated fractional quantum Hall (FQH) liquids is an exciting field of research in a two-dimensional electron system. FQH effect can be explained with the concept of quasi-particles known as composite fermions. Rapidly rotating Bose-Einstein Condensates (BEC), trapped in a a two-dimensional harmonic potential [1] creates a fictitious magnetic field, perpendicular to the 2D-plane that resembles like two-dimensional electron system in the plane perpendicular to the magnetic field. In such a system there is formation of Landau levels due to the perpendicular magnetic field. The correlated FQH-state produced in rotating trapped BEC can be explained theoretically using composite fermions for the Bose atoms [2]. The composite Fermions, bound state of Bose atoms and the odd number of quantized vortices experience a reduced magnetic field $B^* = B - p\rho\phi_0$, where, B represents the fictitious magnetic field, ϕ_0 is the magnetic flux quantum, while the number density of the Bose atoms is ρ, and $p = 1, 3, 5,$ is the odd number of flux quanta. The LL filling fraction of the Bose atoms (ν) can be related with the LL filling fraction of composite Fermions by $\nu = \frac{n}{np+1}$.

In this talk, we will present our numerical study to analyze the collective spin-conserving and spin-reversed excitation spectra in dipolar rotating trapped Bose gas considering the pseudo-spin $1/2$ state [3]. We consider each of the Bose atoms with a dipole moment oriented perpendicular to the trapping potential and they interact with each other via long-ranged dipole-dipole interaction. We have taken into account the lowest possible excitations in our study and calculated the excitation spectra for the three fractions of the first Jain series $\nu = 1/2, 1/4, 1/6$. The lowest-order fundamental mode and the next higher-energy mode of excitation spectra are found for each of the three fractions. In both the spin-reversed and spin conserving excitation we find that the gap between the low lying spectrum decreases significantly with the decrease in the filling fraction. Further we compute the spectral weight for the fundamental mode of excitation, that shows a significant increment in the spectral intensity with decrease with the filling fraction. At the end we provide a possible connection of our observation with the experimental realization.

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Title: Dynamic fluctuations in systems with broken time-reversal symmetry and centre-of-mass conservation

Name: Punyabrata Pradhan

Affiliation: Department of Physics of Complex Systems, S. N. Bose National Centre for Basic Sciences, Kolkata 700106, India.

Abstract: We characterize steady-state static and dynamic properties in a broad class of mass transport processes on a periodic lattice, where both mass and center-of-mass (CoM) remain conserved and detailed balance is violated in the bulk. Using a microscopic approach, we exactly determine the decay (or, growth) exponents for various dynamic and static correlation functions in these systems. We show that, despite constrained dynamics due to the CoM conservation (CoMC), the density relaxation is indeed diffusive. However, fluctuation properties are strikingly different from that in the diffusive systems with a single (mass) conservation law. Indeed, both dynamic and static fluctuations are anomalously suppressed, resulting in an extreme form of *hyperuniformity* in the systems.

Non Equilibrium Dynamics of Interacting Bosons: Steady States and Dynamical Transitions

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We study the non-equilibrium dynamics of an interacting Bose gas with dipole conservation laws in the large N limit. Under a quench dynamics, we find that the system can reach a steady state where dipole conservation is broken, but the U(1) symmetry is preserved. This phase does not occur in the equilibrium phase diagram of the system.

Under a Floquet dynamics, we show that the quasi-steady state at high driving frequencies has a non-monotonic momentum distribution showing clear signatures of athermal behaviour. At low driving frequencies, the system shows dynamical phase transitions where the order parameter vanishes as a function of time in a non-analytic way.

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Study of unzipping transitions in an adsorbed polymer by a periodic force

Abstract

Using Monte Carlo simulations, we study the dynamic transitions in the unzipping of an adsorbed homogeneous polymer on a surface (or wall). We consider three different types of surfaces. One end of the polymer is always kept anchored, and another end monomer is subjected to a periodic force with frequency ω and amplitude g_0. We observe that the force-distance isotherms show hysteresis loops in all three cases. For all three cases, it is found that the area of the hysteresis loop, A_{loop}, scales as $1/\omega$ in the higher frequency regime, and as $g_0^{\alpha}\omega^{\beta}$ with exponents $\alpha = 1$ and $\beta = 1.25$ in the lower frequency regime. The values of exponents α and β are similar to the exponents obtained in the earlier Monte Carlo simulation studies of DNA chains and a Langevin dynamics simulation study of longer DNA chains.

Rejish Nath, IISER Pune

Title: Quantum state engineering in Rydberg atomic arrays

We discuss the different ways in which the quantum states of an atomic array with Rydberg excitations can be engineered. In particular, the use of time-dependent fields and rearrangement of atoms. All these schemes rely on the various avoided crossings in the systems.

Title: Tunable time-crystalline phases in nano-mechanical resonator

Abstract:

Weakly interacting and periodically driven many-body systems can spontaneously break the temporal periodicity of the drive, settling into a collective long-period oscillatory dynamical phase, that bears many surprising similarities to equilibrium thermodynamics phases, in terms of stability, equilibrium fluctuations, robustness to external noise and sharp boundaries at critical parameters marking the symmetry breaking phase transition. Here we will discuss laboratory observation of a range of such exotic time-crystalline phases, in a graphene-Silicon Nitride (SiN) hybrid resonator. Many modes of a large area SiN resonator get weakly coupled via two low-Q broad-band graphene resonator modes, thereby forming the interacting many-body system. When driven parametrically at a frequency that is twice the average frequencies of the resonator modes, we observe sharp phase transitions at critical values of the driving strength, marking the onset of distinct time-crystalline phase. We characterize the states in terms of correlated fluctuations, non-ergodicity, robustness to noise and use an effective mean-field model to identify some of these non-equilibrium states as bifurcations of fixed points and limit cycles. Nevertheless, there are multiple exotic states that require further measurements and analysis for clarity. These time-crystalline states can find numerous applications in processing analog signatures, as frequency references and in sensing and metrology, for the stability, robustness of these phases along with unique non-ergodic frequency features that are highly sensitive to external perturbations at the phase boundaries.

Non-equilibrium Many-Body Physics with ultra-cold Rydberg atoms

Sanjukta Roy
Raman Research Institute, Bangalore

Atoms excited to Rydberg states with high principal quantum numbers have exaggerated properties such as large size, strong dipole-dipole interaction, large values of polarisability and longer lifetimes compared to atoms in their ground state. These exotic characteristics and a high degree of controllability make ultra-cold Rydberg atoms versatile atomic building blocks for various regimes of Quantum Technologies such as scalable quantum information networks, precision Quantum Sensing and Quantum Simulation of Many-body physics.

In this talk, I will give an overview of Quantum Technologies with Rydberg atoms and present our recent results on Doppler-enhanced Quantum magnetometry using Rydberg atoms. I will also present our measurements of the effects of inter-atomic interaction on Autler-Townes splitting in highly-excited cold Rydberg atoms due to strong-field coupling. We explain our observations using theoretical modelling and numerical simulations and find good agreement with our measurements. Finally, I will present our recent progress and future perspectives on Quantum Computing and non-equilibrium Quantum Many-body physics with ultra-cold Rydberg atoms.

The Floquet central spin model: A platform to realize eternal time crystals, entanglement steering, and multiparameter metrology

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We propose and characterize protocols to realize eternal discrete time crystals (DTCs) in the periodically driven central spin model. These eternal DTCs exhibit perfect periodic revivals of the initial state at a time mnT (where $n>1$ and $\{m,n\}\in\mathbb{Z}$), when the Ising interaction strength, λ between the central spin and the satellite spins is tuned to certain values. The combination of perfect initial-state revival and time-translation-symmetry breaking leads to infinitely long-lived oscillations of the stroboscopic magnetization and the entanglement entropy in these DTCs even for a finite number of satellite spins. We analytically determine the conditions for the existence of these eternal DTCs and prove that the system exhibits eternal period-doubling oscillations ($n=2$) when $\lambda=2\pi$ for an arbitrary number of satellite spins. Furthermore, we propose a protocol to realize eternal higher-order(HO)-DTCs ($n>2$) by tuning λ to π. Intriguingly, this protocol naturally steers the system through an entangled trajectory, thereby leading to the generation of maximally entangled Bell-cat states during the dynamical evolution of the HO-DTC. Finally, we demonstrate that these HO-DTCs can serve as a resource for Heisenberg-limited multiparameter sensing.

Sthitadhi Roy
International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru

Title: Imprints of quantum information scrambling on eigenstate correlations

Abstract: How is the spatiotemporal structure of information scrambling imprinted on the eigenstates of quantum many-body systems? This talk will focus on the operator entanglement of the time-evolution operator as a key measure of information scrambling, demonstrating how it encodes the spatial and temporal patterns of this phenomenon. We will then explore the connections between operator entanglement and other more commonly employed measures, such as out-of-time-ordered correlators and dynamical two-point correlation functions. We will show how eigenstate correlations provide a unifying framework for understanding these measures. Finally, I will present exact results for relevant eigenstate correlations in the context of a minimal circuit model that exhibits maximal quantum chaos.

Title: Non equilibrium and non linear dynamics of atom photon interacting system

Abstract: We consider a coupled atom-photon interacting system described by a dimer of anisotropic Dicke model in the presence of photon loss, exhibiting a rich variety of non equilibrium phases and nonlinear dynamics. A key feature of this system is the multistability of different dynamical states, particularly the coexistence of various superradiant phases.

Remarkably, this dimer system manifests self-trapping phenomena, resulting in a photon population imbalance between the cavities. Additionally, we identify a unique class of oscillatory dynamics, “self-trapped limit cycle,” hosting self-trapping of photons.

The absence of stable dynamical phases leads to the onset of chaos, which is diagnosed using the saturation value of the decorrelator dynamics.

Moreover, in an array of cavity systems described by the Tavis-Cummings-Hubbard model, we demonstrate the emergence of a quasi-steady state in a dissipative environment that exhibits intriguing ergodic behavior.

Exotic phases in non-Hermitian extended SSH models

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We explore the effects of non-reciprocal hopping in the extended Su-Schrieffer-Heeger (SSH) models, considering four sub-lattices in a unit cell and second-nearest-neighbor intercell hopping for SSH4 and SSH long-range (SSHLR) models, respectively [1]. We first study the bulk-boundary correspondence of the non-Hermitian topological phase by comparing the open boundary end modes and bulk invariant computed in a generalized Brillouin zone. Interestingly, the bulk-boundary correspondence is restored for the SSH4 while there exist challenges in SSHLR model, caused by the multi-valuedness of the non-Bloch momentum in generalized Brillouin zone for the next-nearest neighbor coupling. Furthermore, winding numbers obtained from different off-diagonal blocks of the Hamiltonian can differ, revealing a richer and more intricate topological structure only for the SSHLR model. Thereafter, we extend the concept of charge transport in the NH models under adiabatic driving where quantized nature of charge transport can be understood from the non-Bloch Chern number and non-Hermtian Bott index. The adiabatic evolution of zero-modes can be explained by the bulk-boundary correspondence which is substantailly richer in SSHLR model than that of the SSH4 model. Our study sheds light on the non-Hermiticity mediated topological phases in static as well as driven extended SSH models [2].

[1] D. Joshi, T. Nag, arXiv:2503.18125.
[2] D. Joshi and T. Nag under preparation (2025).

Name: Tapan Mishra
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Title: Arresting the dynamics of magnon bound state by relaxing kinetic constraint.

Abstract: Non-equilibrium dynamics of many-body quantum systems reveal interesting scenarios and have been the topic of intense research in recent years. However, such problems are often found to be challenging to address both theoretically and experimentally. In this context, the dynamics of few interacting particles or the quantum walk provides a bottom-up approach to understand many-particle dynamics and at the same time reveal novel phenomena which are completely different from their many-body counterparts. In this talk, we will discuss the dynamics of a magnon bound state or a bound states of two nearest neighbour spin excitation on a spin chain. We will show that the bound state exhibits slower dynamics compared to the individual spin excitations when only nearest neighbour hopping is allowed. While this is expected, we will show that the dynamics exhibits counter-intuitive features when the nearest-neighbour kinetic constraint is relaxed. We will discuss our findings obtained using both classical and quantum computing simulations.